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PREALIGNMENT B(E2)-ANOMALY IN ^{124}Xe

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Lifetimes of 17 levels of ^{124}Xe were measured using the Recoil Distance Doppler Shift method. An anomalous E2-reduction was observed, starting at $I^\pi = 8^+$ and $I^\pi = 5^+$ in the groundstate and in the quasi-gamma band respectively. This anomaly is discussed in terms of the Interacting Boson Model.

The irregularities in the yrast cascades of even–even nuclei, known as backbending, are nowadays commonly understood as a band crossing phenomenon, dominated by the rotation-alignment (RAL) of a high-j broken pair [1]. According to the band crossing description, the E2 transition probability between yrast states must sharply drop at backbending, while the transitions below and above the crossing should have the full rotational strength [2]. However, the measurement of B(E2) values in ^{126}Ba [3] and $^{130-134}$Ce [4] have displayed an anomaly, viz. the transition strength is substantially reduced even below the band crossing. This anomaly can not be explained by Nilsson model band crossing calculations [2], indicating that the backbending pattern and the B(E2) anomaly may have different origins.

A possible theoretical explanation was provided by Draayer et al. [5] who also coined the expression "prealignment B(E2) anomaly". The authors carried out a pseudo-SU(3) shell model calculation for ^{126}Ba. The anomaly is primarily related to the crossing of two SU(3) representations.

The aim of the present work has been to bring new experimental information on the prealignment B(E2) anomaly by studying ^{124}Xe and to perform a detailed comparison of the results with Interaction Boson Model (IBM) calculations.

The nucleus ^{124}Xe was produced in the following reactions: ^{122}Te (α, 2n) ^{124}Xe (E_α = 24, 25 MeV), ^{108}Pd (^{19}F, p2n)^{124}Xe(E ^{19}F = 60–75 MeV) and ^{114}Cd (^{13}C, 3n) ^{124}Xe(E ^{13}C = 46–58 MeV). Gamma singles, γ–γ coincidences, angular distributions, excitation functions and conversion electrons were measured at the FN Tandem Van de Graaff accelerator in Cologne in order to establish an extended level scheme. In the low spin part it agrees well with those given elsewhere [6,7]. A detailed discussion will be given in a forthcoming paper [8].

The lifetimes of 17 levels were measured by means of the Recoil Distance Doppler Shift (RDDS) technique, using the reaction ^{114}Cd (^{13}C, 3n) ^{124}Xe at E ^{13}C = 54.4 MeV. The gamma-rays were detected by three large volume Ge (Li) detectors at 0°, 160° and 305° relative to the beam axis. The intensities of the shifted and unshifted peaks were extracted from the RDDS spectra by the procedure described in ref. [9].

The resulting B(E2) values in WU are given in fig.

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1. It should be mentioned that our result for the $B(\mathrm{E2}, 2 \rightarrow 0)$ differs considerably from that given previously [10]. Moreover it does not fit so well into the trend of the systematic IBM calculations of ref. [11]. Hence we checked very carefully the validity of our results. From the independent analysis of the RDDS spectra taken at different angles deorientation effects due to the hyperfine field could be excluded. No essential influence from short lived sidefeeding components can be expected as from the detailed level scheme an upper limit of 3% can be set on the relative intensity of unobserved side feeding to the 2^+ state.

For the discussion of the level structure the excited states were tentatively grouped into bands using the experimental $B(\mathrm{E2})$ values (fig. 1). The groundstate band, whose transitions are characterized by rather large $B(\mathrm{E2})$'s can be followed up to the 8^+ state. The 10^+ state appears to be the head of a new band as indicated by the small $B(\mathrm{E2})$ value of 24 WU of the $10^+ \rightarrow 8^+$ transition. It is supposed to be a $(\nu h_{11/2})^{-2}$ excitation: if we calculate the aligned angular momentum of the two $h_{11/2}$ quasiparticles by using the method given in ref. [12], we find the value $i = 7.1\ \hbar$ which is typical for a situation where the $h_{11/2}$ subshell is partially filled: the extrapolated gsb was used as reference line. This suggests that we deal with an aligned two-neutron state. An additional support to this interpretation may be provided by the fact that in the $h_{11/2}$ neutron bands of ^{121}Xe and ^{123}Xe [8] no backbending has been observed.

The pattern of excitation energies and $B(\mathrm{E2})$ values (fig. 2) is very similar to that of the isotope ^{126}Ba [3], and the prealignment $B(\mathrm{E2})$ reduction is clearly evident. We tried to achieve a consistent description of both energies and transition rates in ^{124}Xe and ^{126}Ba by using the model described in ref. [13], which

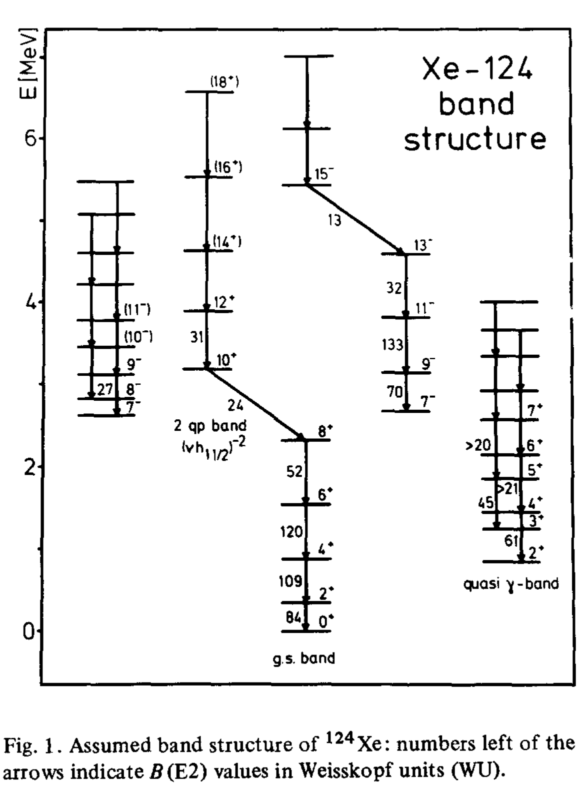

Fig. 1. Assumed band structure of ^{124}Xe: numbers left of the arrows indicate $B(\mathrm{E2})$ values in Weisskopf units (WU).

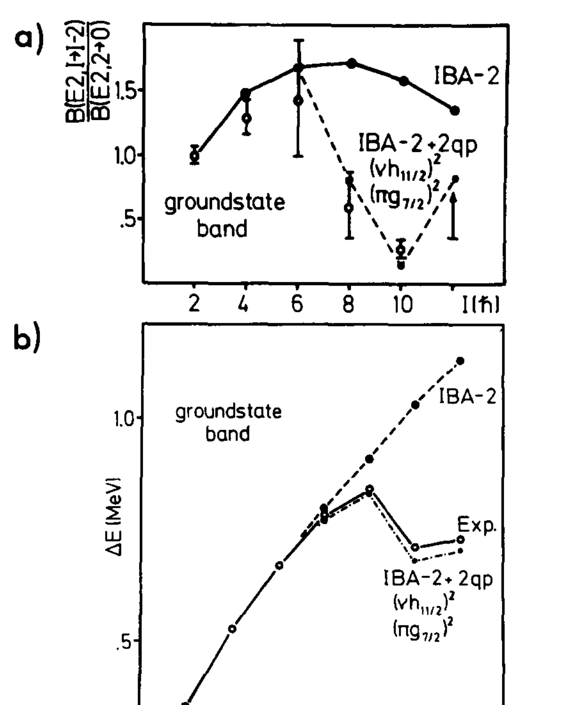

Fig. 2. (a) Experimental E2 transition strengths compared with the predictions for the IBA2 + 2 qp model. For the two quasiparticles the configurations $(\nu h_{11/2})$ and $(\pi g_{7/2})$ are considered. The transition probabilities are normalized to the $B(\mathrm{E2}, 2^+ \rightarrow 0^+)$ value. (b) Comparison of the resulting transition energies with experiment.

constitutes an extension of the IBM [14] and of previous more simple minded calculations [15]; a model similar to that of ref. [13] was given in ref. [16]. One core boson can be broken into two particles which are recoupled to form a pair with higher angular momentum. Thus in addition to the space of N bosons, the model space includes states in which the particle pair is coupled to $N-1$ bosons of the core. This model was shown to account well for the salient features of backbending [13,7] as far as excitation energies are concerned, but it fails to reproduce the anomalous behaviour of the transition rates. Hence the calculations of ref. [13] have been extended by considering mixing with both two-neutron and two-proton bands. In one calculation a broken $(\pi g_{7/2})$ pair has been considered alongside of a $(\nu h_{11/2})$ pair.

The model hamiltonian is [13]

$$H = H^{\mathrm{B}} + H^{\mathrm{F}} + H^{\mathrm{BF}} ,$$

where H^{B} is the energy of the boson core, H^{F} that of the two fermions. The interaction of the core with the fermions is given by

$$V^{\mathrm{BF}} = KQ_{\pi} \cdot Q_{\nu}$$

where Q is a generalized quadrupole operator

$$Q_{\rho} = Q_{\rho}\ (\text{boson}) + \alpha_{\rho}\, [a_{\rho}^{+} a_{\rho}^{+}]^{(2)} + \beta_{\rho}\, [[a_{\rho}^{+} a_{\rho}^{+}]^{(4)} d_{\rho}]^{(2)}$$
$$- \beta_{\rho} a_{\rho}^{+} [[\tilde{a}_{\rho} \tilde{a}_{\rho}]^{(4)}]^{(2)} \qquad (\rho = \pi, \nu) ,$$

with a_{jm}^{+} being the nucleon creation operator $[a_{jm} = (-1)^{j-m} a_{j-m})$ and d^{+} the d-boson creation operator; the quadrupole coupling parameter K has the same value as in H_{B}.

The parameters of H_{B} for ^{124}Xe and ^{126}Xe were taken from ref. [11]; those of the ^{122}Te core were fitted to the low spin states of ^{122}Te. The parameters of V^{BF} were $K = -0.1430$, $\alpha_{\pi} = 1.06$, $\alpha_{\nu} = 1.76$, $\beta_{\pi} = \beta_{\nu} = 0.032$ (all values in MeV). The diagonal matrix elements of H_{F} were: $E(4) = 1.716$, $E(6) = 2.553$ for $(\pi g_{7/2})^2$ and $E(4) = 1.804$, $E(6) = 2.223$, $E(8) = 3.144$, $E(10) = 3.694$ for $(\nu h_{11/2})^{-2}$ (angular momentum of the state in paranthesis). This choice of parameters allowed to reproduce the ^{124}Xe levels, as well as the B(E2) values (fig. 2). The attempt to fit energies and B(E2)'s in ^{126}Ba with the same parameters was much less successful.

The squared amplitudes of the pure boson and of the two-particle components are given in table 1. It can be seen that the 8^+ and 10^+ states have a complicated structure. For both spins, pairs of nearly degenerate levels should exist, in disagreement with experiment.

Table 1
Probabilities of components of yrast states in ^{124}Xe (in %)

I	N bosons only	$(N-1)$ bosons $\otimes (\pi g_{7/2})$	$(N-1)$ bosons $\otimes (\nu h_{11/2})^{-2}$
0	99.99	0.01	0
2	99.98	0.02	0
4	99.88	0.11	0.01
6	99.07	0.91	0.02
8	35.06	64.91	0.02
10	1.38	17.11	81.51
12	0.01	0	99.99
14	0	0	100.00

The magnetic moments of the 8^+ and 10^+ states are expected to deviate strongly from the collective values: the 8^+ state should have a large positive contribution from $(\pi g_{7/2})^2$, whereas a small negative value of g(10^+) should follow from the contribution of $(\nu h_{11/2})^{-2}$. An experimental determination of these moments is therefore highly desirable. The discrepancies mentioned above show that this description is not completely satisfactory.

It is obvious that the model is oversimplified. Only one pair has been broken. However, it has been shown [17], that the scattering of several pairs from the core to the valence shell must be taken into account in a correct description of backbending.

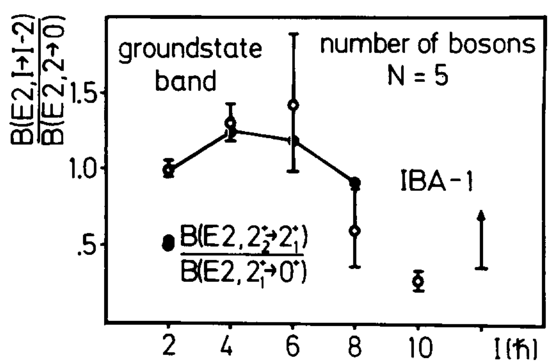

Fig. 3. Experimental E2 transition strengths compared with theoretical values from the collective IBM calculation; states with $I > 8$ which are mixed have not been represented.

A different approach has been considered [18], based on a microscopic calculation. While in IBM the boson cutoff is mainly due to the finite number of valence particles, the effect of the Pauli principle has been considered explicitly. The results of the calculation are equivalent to introducing an effective boson number around $N = 5$. The influence of this reduction of the effective boson number of the transition probabilities between collective states calculated by means of IBM can be seen in fig. 3.

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